APPENDIX E
FISH PASSAGE FLOWS

E Fish Passage Flows

E.1 Overview of Hydrologic Methods

This section presents three methods to calculate high and low design flows for road crossings where fish passage is a requirement. Design flows can be determined using the 1) USGS regional regression equations; 2) local stream gage data to estimate annual exceedance factors and 3) the Natural Resources Conservation Service (NRCS) Urban Hydrology for Small Watersheds Technical Release 55 (TR-55).

A general discussion on the hydrologic process is not presented in this section because numerous textbooks discuss the hydrologic process in detail. It is assumed that the traffic engineer has had at least one university level class covering hydrology and hydraulics. As a refresher, a good discussion on hydrology is presented in Chapter 810 of the Caltrans Highway Design Manual (HDM). The HDM should be readily available to all Caltrans engineers and it is highly recommended that Chapter 810 is read by the traffic engineer before beginning any hydrologic analysis.

Additional references required by the traffic engineer include:

- A hydrology text or manual that includes discussion on coefficients such as Manning's roughness values.
- The Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55 (TR-55). This document can be found at the U.S. Department of Agriculture's website http://www.info.usda.gov/CED/
- Rantz, S.E., 1969, Mean annual precipitation in the California region: U.S. Geological Survey Open-File Map (Reprinted 1972, 1975).
- Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973, Precipitation – Frequency Atlas of the Western United States, Volume XI – California, NOAA.

E.2 Selecting the Appropriate Method

In most instances, watershed characteristics control which hydrologic method is used for analysis. Contributing to the method selection is the available information for the watershed. For instance, it is unlikely that a stream gage would be located at or even near the stream crossing under consideration. Gage data is typically recorded on large streams where stream crossings have already been designed and constructed.

Table 1 below provides guidance on which method is appropriate to use based on the watershed characteristics and available information.

Table E-1. Guidance on use of methods.

Method	Assumptions	Data Needed
Exceedance**	▪ At least five years of recorded daily average flows, and preferably more than ten-years (do not need to be consecutive years) ▪ Drainage area less than 129.5 km^2 (50 mi^2) (preferably less than 25.9 km^2 (10 mi^2)) ▪ Unregulated flows (no upstream impoundment or water diversions)	▪ Gage Data from nearby stream ▪ Drainage area of both watersheds
Regional Regression*	▪ Catchment area limit varies by region ▪ Ungaged channel ▪ Basin not located on floor of Sacramento and San Joaquin Valleys ▪ Peak discharge value for flow under natural conditions unaffected by urban development and little or no regulation by lakes or reservoirs	▪ Drainage area ▪ Mean annual precipitation ▪ Altitude Index
TR-55*	▪ Small or midsize catchment (< 8 km^2 (< 3.1 mi^2)) ▪ Concentration time range from 0.1 to 10-hour (tabular hydrograph method limit < 2 hour) ▪ Runoff is overland and channel flow ▪ Simplified channel routing ▪ Negligible channel storage	▪ 24-hour rainfall ▪ Rainfall distribution ▪ Runoff curve number ▪ Concentration time ▪ Drainage area

*Refer to the Caltrans Highway Design Manual for further information

**Refer to the California Salmonid Stream Habitat Restoration Manual for further information

In determining the high fish passage flows for design, if stream gage data is available, the exceedance flow method should be used to calculate a percent exceedance flow. Using Table 2 below, the percentages are listed for each fish species. If stream gage data is not available, then the recurrence intervals for the 2-year and 100-year flow should be calculated using either the regional regression or TR-55 methods and a percentage of the 2-year is used for high fish passage design flows.

Table E-2. High design flow for fish passage.

Species/Life Stage	Exceedance Flow	Percentage of 2-year Recurrence Interval
Adult Anadromous Salmonids	1%	50%
Adult Non-Anadromous Salmonids	5%	30%
Juvenile Salmonids	10%	10%
Native Non-Salmonids	5%	30%
Non-Native Species	10%	10%

In determining lower fish passage flow, again, if stream gage data is available, the exceedance flow method should be used to calculate a percent exceedance flow. If the exceedance flow is determined to be less than the Alternate Minimum Flow (shown in Table 3), then the alternate minimum flow should be used.

Table E-3. Low design flow for fish passage.

Species/Life Stage	Exceedance Flow	Alternative Minimum Flow	
		(ft^3/s)	(m^3/s)
Adult Anadromous Salmonids	50%	3	0.08
Adult Non-Anadromous Salmonids	90%	2	0.06
Juvenile Salmonids	95%	1	0.03
Native Non-Salmonids	90%	1	0.03
Non-Native Species	90%	1	0.03

The exceedance flow, regional regression, and TR-55 methods for determining flows are presented in detail in the following sections.

E.3 Exceedance Flow Rates using Gage Data

E.3.1 Method Description

The upper fish passage flow limit for adult anadromous salmonids is defined as the 1 percent exceedance flow (or the flow equaled to or exceeded 1 percent of the time). The lower fish passage flow equals the 50 percent exceedance flow. Figure 1 below shows a typical distribution of flow data and the exceedance intervals. These exceedance flows rates are not to be confused with calculating an exceedance flow probability which requires a statistical analysis using annual peak flows.

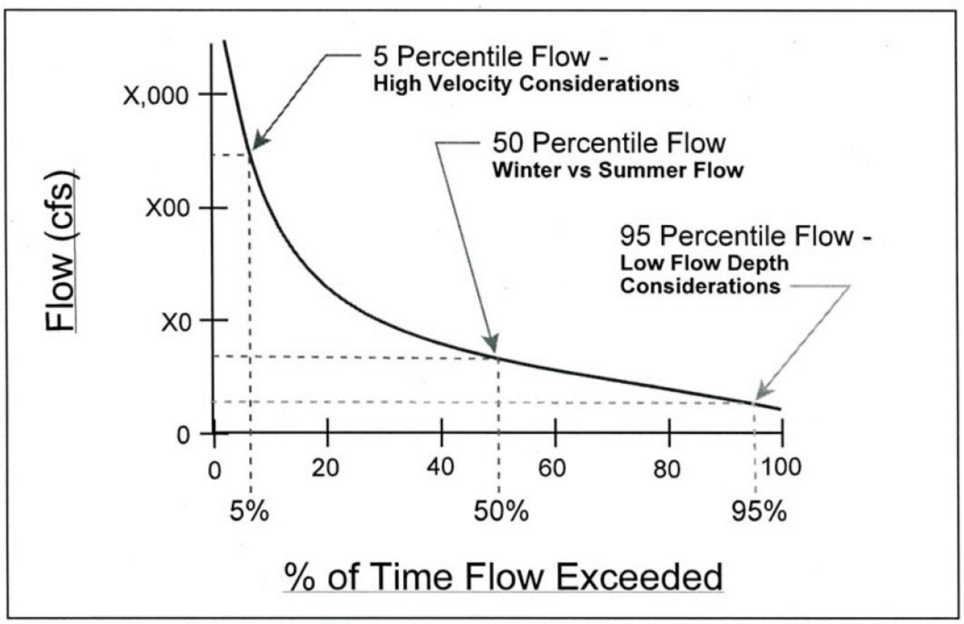

Figure E-1. Example of a flow duration curve.

Source: California Salmonid Stream Habitat Restoration Manual, 2003.

Identifying exceedance flows requires obtaining average daily stream flow data. If the stream flow rate is known based on gage data collected for that stream, then the crossing should be sized based on that data. Often times, a crossing is to be designed on a stream where gage data is not available. However, if a nearby stream has gage data and the stream where the crossing is to be designed has similar watershed characteristics, then the available gage data can be adjusted and used for design. The method presented below describes how to adjust nearby stream gage data to estimate the peak stream flow rate. The following method was abstracted from Section IX of the California Salmonid Stream Habitat Restoration Manual. For more information please reference the Manual.

1. Flow records for nearby streams should be acquired from the USGS and/or the California Department of Water Resources. The information must meet the following requirements:
   - At least 5-years of recorded daily average flows, and preferably more than 10-years (do not need to be consecutive years)
   - A drainage area less than 50 square miles (130 km^2), and preferably less than 10 square miles (26 km^2)
   - Unregulated flows (no upstream impoundment or water diversions). If feasible, use several gaged streams to determine which ones have flow characteristics that best resemble stream flows observed throughout the project area.
2. Rank the flows from highest to lowest (a rank of i=1 given to the highest flow). The lowest flow will have a rank of *n*, which equals the total number of flows considered. To identify rank associated with a particular exceedance flow, such as the 50 percent and 1 percent exceedance flows ($i_{50\%}$ and $i_{1\%}$) respectively, use the following equations:

   $i_{50\%} = 0.50(n+1)$ $\qquad$ $i_{1\%} = 0.01(n+1)$
3. Round values to the nearest whole number. The flows corresponding to those ranks are the 50 percent and 1 percent exceedance flows for the gaged stream.
4. To apply these flows to the ungaged stream, multiply the flows obtained in the above step, $Q_{50\%}$ and $Q_{1\%}$, by the ratio of the gaged stream's drainage area (DA) to the drainage area of the ungaged stream at the stream crossing. Multiplying by this ratio adjusts for the differences in drainage area between watersheds.

Other methods for determining exceedance flows for ungaged streams can also be used. These methods typically take into account differences in precipitation between watersheds.

When flows from several different gaging stations are available, use knowledge of the local hydrology and rainfall patterns to decide which one offers the best estimate. For inventory and assessment purposes, the method described above is often sufficient. More detailed or accurate flow measurement techniques may be necessary in the design of new or replacement stream crossings.

Other things to consider when using gage data includes:

- This method is limited in a number of ways, one of which is the fact that it only considers a narrow time frame in the life time of the stream crossing. For example, stream flow data may have only been collected during a drought. This would result in sizing a fish passage that is too small. Inversely, the fish passage could be sized too large if the gage data was taken during years of high rainfall.

- A second limitation of this method is the transfer of stream flow data from one watershed to another. Although the watersheds may be near each other, there will still be differences between the two. Cover, detention, soil type, slope, and even rainfall could vary between the two watersheds. Careful inspection of the two watersheds should be conducted to determine if it is reasonable to transfer the data.

E.3.2 Example Calculation – Exceedance Flow Rate Using Gage Data

For this example a stream is located in Santa Barbara County with a drainage area of 35.6 mi^2. There is no gage data available for this stream, but a nearby stream with similar watershed characteristics has gage data available. Data was collected by USGS gage number 11132500 for daily average streamflow between the dates of 10/01/1987 and 10/01/2002. This information was downloaded from the USGS website. There was a total of 5480 data points. The drainage area for this gage is 47.1 square miles.

There is more than ten years of recorded daily average flow available for a nearby stream, the drainage area of the stream of interest is less than 31 mi^2, and both streams have unregulated flow. Based on the criteria stated in Section 2, the exceedance flow rate method is most appropriate for this case.

The data was sorted from high to low. Each data point was assigned a rank; the highest value was assigned one and the lowest value was assigned 5480. The 50% and 1% exceedance values were determined using the following equations:

$$i_{50\%} = 0.50(5480+1)$$
$$i_{1\%} = 0.01(5480+1)$$

$$i_{50\%} = 2741$$
$$i_{1\%} = 55$$

Looking up these flow values in the ranked table yields:

Flow	Rank
1.8	2737
1.8	2738
1.8	2739
1.8	2740
1.8	2741
1.8	2742
1.8	2743

Flow	Rank
294	52
293	53
285	54
283	55
279	56
267	57
264	58

The corresponding flow rates at these rankings are:

$$Q_{50\%} = 1.8 \text{cfs}$$

$$Q_{1\%} = 283 \text{cfs}$$

These values need to be adjusted down based on the differences between the drainage areas:

$$Q_{50\%} = 1.8\text{cfs}\left(\frac{35.6\text{ mi}^2}{47.1\text{ mi}^2}\right)$$

$$Q_{1\%} = 283\text{cfs}\left(\frac{35.6\text{ mi}^2}{47.1\text{ mi}^2}\right)$$

$$\underline{\underline{Q_{50\%} = 1.4\text{ cfs}}}$$

$$\underline{\underline{Q_{1\%} = 213.9\text{ cfs}}}$$

E.4 Regional Regression Equations

E.4.1 Method Description

Regional Regression equations have been developed for the state of California to estimate the peak discharge for a watershed for recurrence intervals of 2, 5, 10, 25, 50, and 100 years. The state is divided into six hydrologic regions and each region has specifically derived equations unique to that region. A map showing the different regions is shown in Figure 2. The parameters for the equations include drainage area (A), in square miles; mean annual precipitation (P), in inches; and an altitude index (H), which is the average altitudes in thousands of feet at the points along the main channel at 10 percent, and 85 percent of the distances from the site to the divide (USGS 1993).

Area and altitude index are determined from a topographic map, and mean annual precipitation is determined from a map in Rantz (1969). The USGS provides non-proprietary software that may be used to calculate the flows using the regression equations. The software is available at their website, www.usgs.gov, and is called the National Flood Frequency Program (NFF). The following equations are used to calculate the design flow rates for the six hydrologic regions in California.

Figure E-2. Flood-frequency region map for California.

Source: http://water.usgs.ca.gov/software/nff_manual/ca/index.html

North Coast Region

$$Q_2 = 3.52A^{0.90}P^{0.89}H^{-0.47}$$
$$Q_5 = 5.04A^{0.89}P^{0.91}H^{-0.35}$$
$$Q_{10} = 6.21A^{0.88}P^{0.93}H^{-0.27}$$
$$Q_{25} = 7.64A^{0.87}P^{0.94}H^{-0.17}$$
$$Q_{50} = 8.57A^{0.87}P^{0.96}H^{-0.08}$$
$$Q_{100} = 9.23A^{0.87}P^{0.97}$$

In the North Coast region, use a minimum value of 1.0 for the altitude index (H).

Northeast Region

$$Q_2 = 22A^{0.40}$$
$$Q_5 = 46A^{0.45}$$
$$Q_{10} = 61A^{0.49}$$
$$Q_{25} = 84A^{0.54}$$
$$Q_{50} = 103A^{0.57}$$
$$Q_{100} = 125A^{0.59}$$

Maximum drainage basin is 40 km^2 for the Northeast region.

Sierra Region

$$Q_2 = 0.24A^{0.88}P^{1.58}H^{-0.80}$$
$$Q_5 = 1.20A^{0.82}P^{1.37}H^{-0.64}$$
$$Q_{10} = 2.63A^{0.80}P^{1.25}H^{-0.58}$$
$$Q_{25} = 6.55A^{0.79}P^{1.12}H^{-0.52}$$
$$Q_{50} = 10.4A^{0.89}P^{1.03}H^{-0.41}$$
$$Q_{100} = 15.7A^{0.77}P^{1.02}H^{-0.43}$$

Central Coast Region

$$Q_2 = 0.0061A^{0.92}P^{2.54}H^{-1.10}$$
$$Q_5 = 0.118A^{0.91}P^{1.95}H^{-0.79}$$
$$Q_{10} = 0.583A^{0.90}P^{1.61}H^{-0.64}$$
$$Q_{25} = 2.91A^{0.89}P^{1.26}H^{-0.50}$$
$$Q_{50} = 8.20A^{0.89}P^{1.03}H^{-0.41}$$
$$Q_{100} = 19.7A^{0.88}P^{0.84}H^{-0.33}$$

South Coast Region

$$Q_2 = 0.14A^{0.72}P^{1.62}$$
$$Q_5 = 0.40A^{0.77}P^{1.69}$$
$$Q_{10} = 0.63A^{0.79}P^{1.75}$$
$$Q_{25} = 1.10A^{0.81}P^{1.81}$$
$$Q_{50} = 1.50A^{0.82}P^{1.85}$$
$$Q_{100} = 1.95A^{0.83}P^{1.87}$$

South Lahontan-Colorado Desert Region

$$Q_2 = 7.3A^{0.30}$$
$$Q_5 = 53A^{0.44}$$
$$Q_{10} = 150A^{0.53}$$
$$Q_{25} = 410A^{0.63}$$
$$Q_{50} = 700A^{0.68}$$
$$Q_{100} = 1080A^{0.71}$$

Maximum drainage basin is 40 km^2 for the South Lahontan-Colorado Desert regions.

Where:

A = Drainage area, mi^2

P = Precipitation, inches

H = altitude index

Other things to consider when using the Regional Regression equations include:

- Ground conditions play a significant role in the peak flow rate of a stream. Bare ground with little infiltration and a steep slope will result in a higher peak flow rate because water will reach the point of interest faster than the same area that has lush ground cover, absorbent soils, and a flat slope.
- Drainage area and altitude index are easily calculated from a topographic map. Mean annual precipitation, on the other hand, is a general estimate for an area and not specific to a particular watershed. Rainfall amounts collected at various gages throughout a region are extrapolated over that region to get isohyets, or lines of equal rainfall. Mean annual precipitation for a region is based on these isohyets that are drawn from information collected over a number of years. A number of publications can be consulted for further discussion on the derivation and applicability of mean annual precipitation.
- Inherent in the regression equations are errors of estimate. According to the USGS, the standard error of estimate for the California regression equations ranges from 60 to 100 percent.
- Regression equations should be used when little is known about the watershed. If sufficient information about the watershed is available, use of the other methods described in this section is recommended for analysis.
- For more information of the development and use of regression equations refer to the U.S. Geological Survey Water-Resources Investigations Report 94-4002.

E.4.2 Example Calculation - Regional Regression Method

Lower fish passage flows are for the 50% exceedance probability values, which is equivalent to a 2 year recurrence interval. The 1% exceedance probability is equivalent to a 100-year event. For this example, a stream is located in Humboldt County which is in the North Coast hydrologic region according to the regional regression map (Shown on page X). The stream is not located on the floor of the Sacramento and San Joaquin Valleys and there is no gage data available. This stream fits the regional regression method well based on criteria listed in the table in Section 4. The 2-year and 100-year recurrence interval regression equations for this region are:

$$Q_2 = 3.52A^{0.90}P^{0.89}H^{-0.47}$$
$$Q_{100} = 9.23A^{0.87}P^{0.97}$$

The watershed characteristics for the area are as follows:

Drainage Area (A) = 248 miles

2-Year, 24-hour Rainfall (P_2) = 4 in
100-Year, 24-hour Rainfall (P_{100}) = 8 in
Source: NOAA Atals

Average elevation at 10 percent = 125 feet
Average elevation at 85 percent = 210 feet
Source: Topographic map

Altitude Index H = 125+210/2 = 167.5 feet = 0.1675 thousands feet

Plugging in the drainage area and the appropriate precipitation into the equation results in:

$$Q_2 = 3.52\left(248\ \text{mi}^2\right)^{0.90}\left(4\ \text{in}\right)^{0.89}(0.1675)^{-0.47}$$
$$Q_{100} = 9.23\left(248\ \text{mi}^2\right)^{0.87}\left(8\ \text{in}\right)^{0.97}$$

$$\underline{\underline{Q_2 = 4{,}000\ \text{cfs}}}$$
$$\underline{\underline{Q_{100} = 8{,}402\ \text{cfs}}}$$

E.5 TR-55 Method

E.5.1 Method Description

The TR-55 method presents simplified procedures for estimating runoff and peak discharges in small watersheds. The method is geared towards estimating runoff in urban and urbanizing watersheds; however, the procedures apply to any small watershed in which certain limitations are met.

The method begins with the assumption that rainfall is uniformly imposed on the watershed over a specified time distribution. TR-55 includes four regional rainfall time distributions for a 24-hour period. The rainfall distributions were designed to contain the intensity of any duration of rainfall for the frequency of the event chosen.

Mass rainfall is converted to mass runoff by using a runoff curve number (CN). CN is based on soils, interception, and surface storage. Runoff is then transformed into a hydrograph by using unit hydrograph theory and routing procedures that depend on runoff travel time through segments of the watershed (TR-55 1986).

Three steps are performed to calculate the peak discharge of a drainage area. The three steps are to calculate the Q in inches, calculate the time of concentration in hours, and then calculate the peak discharge. The three steps are described in the following sub-sections.

The TR-55 method is used for a single hydrologically homogenous watershed. If the watershed is heterogeneous, made up of several homogenous subareas, then the TR-55 publication should be consulted. TR-55 also addresses how to use detention basins to reduce the peak flow rate of an urbanizing watershed.

E.5.2 SCS Runoff Curve Number

The SCS runoff equation, which calculates Q in inches, is

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Where Q equals runoff (in), P equals rainfall (in), S equals potential maximum retention after runoff begins (in), and I_a equals initial abstraction (in).

Initial abstraction is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. Through studies of many small agricultural watersheds, I_a was found to be approximated by the following empirical equation:

$$I_a = 0.2S$$

Combing these two equations results in the following equation:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

S is related to the soil and cover conditions of the watershed through the CN. CN has a range of 0 to 100, and S is related to CN by:

$$S = \frac{1000}{CN} - 10$$

Figure 3 and Table 4 solve the above equations for a range of CNs and rainfall.

Parameters used to determine CN include hydrologic soil group (HSG), cover type, treatment, hydrologic condition, antecedent runoff condition (ARC), and whether the runoff passes over an impervious area directly connected to a drainage system (connected) or spread over a pervious area before connecting to a drainage system (unconnected) area before entering the drainage system. These parameters must be determined through investigation of the drainage area. Figure 4 is used to determine which figure or table to use in choosing a CN. Tables 5 through 8 assume impervious areas that are directly connected. The following sub-sections describe each parameter used to determine CNs and how to modify them for urban conditions.

E.5.3 Hydrologic Soil Groups (HSG)

Soils are classified into four HSG's (A, B, C, and D) according to their minimum infiltration rate. The soils of interest may be identified from a soil report, which can be obtained from local NRCS offices or soil and water conservation district offices.

E.5.4 Cover Type

Cover can be determined by field reconnaissance, aerial photography, and land use maps. Tables 5 through 8 addresses most cover types, such as vegetation, bare soil, and impervious surfaces.

E.5.5 Treatment

Treatment is a cover type modifier to describe the management of cultivated agricultural lands as seen in Table 6.

E.5.6 Hydrologic Condition

Hydrologic condition relates to the density of plant and residue cover on sample areas. Good hydrologic condition indicates that the soil usually has a low runoff potential. Some factors to consider in estimating the effect of cover on infiltration and runoff are (a) canopy or density of lawns, crops, or other vegetative areas; (b) amount of year round cover; (c) amount of grass close-seeded legumes in rotations; (d) percent of residue cover; and (e) degree of surface roughness.

E.5.7 Antecedent Runoff Condition (ARC)

ARC is an attempt to account for the variation in CN at a site from storm to storm. The CN's in Tables 5 through 8 are for average ARC, which is used primarily for design applications.

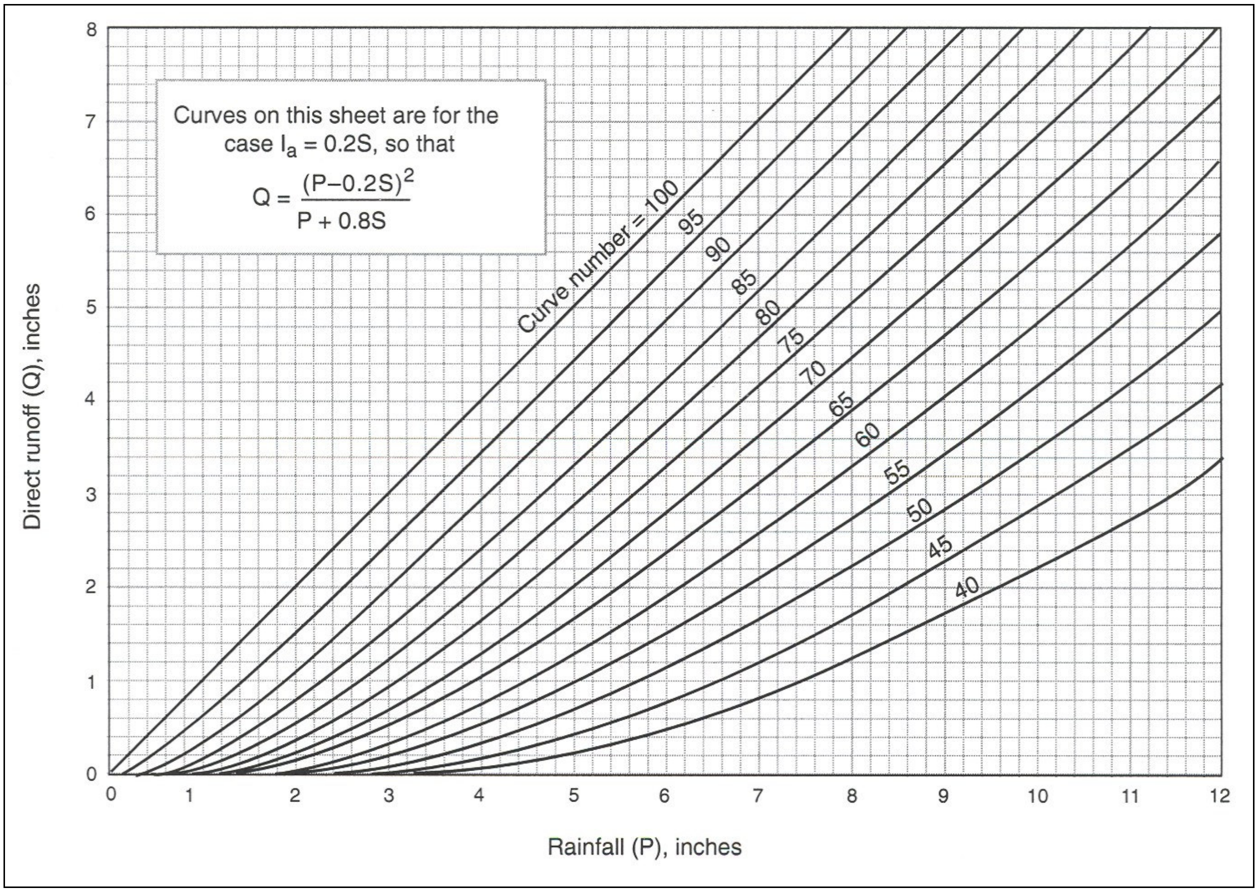

Figure E-3. Solution of runoff equation.

Source: TR-55, 1986.

Table E-4. Runoff depth for selected CNs and rainfall amounts.

Source: TR-55, 1986.

Rainfall	Runoff depth for curve number of—												
	40	45	50	55	60	65	70	75	80	85	90	95	98
	inches												
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

1/ Interpolate the values shown to obtain runoff depths for CN's or rainfall amounts not shown.

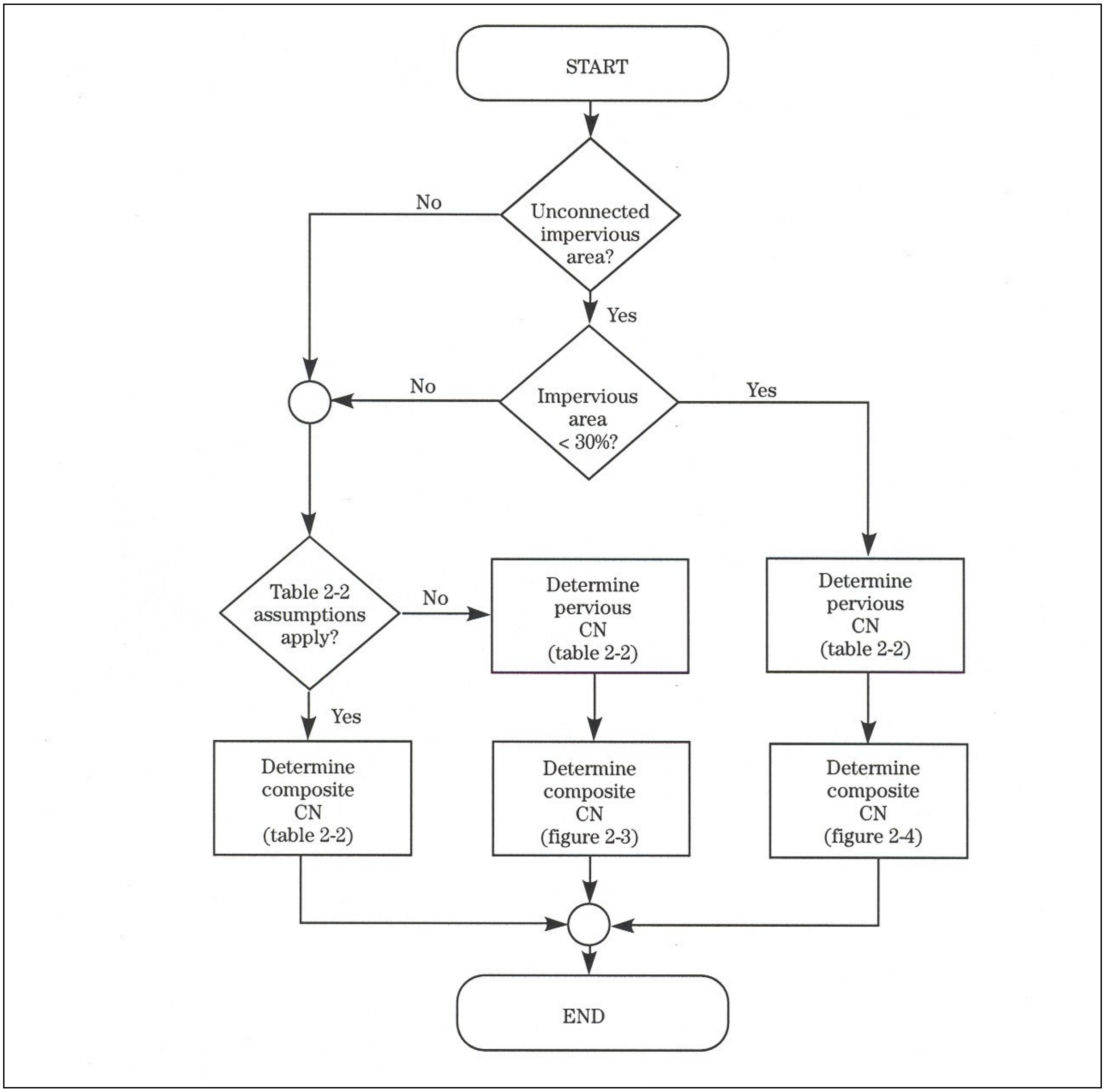

Figure E-4. Flow chart for selecting the appropriate figure or table for determining runoff curve numbers.

Source: TR-55, 1986.

Table E-5. Runoff curve numbers for urban areas.

Source: TR-55, 1986.

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

1 Average runoff condition, and $I_a = 0.2S$.
2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.
3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.
4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.
5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Table E-6.Runoff curve numbers for cultivated agricultural lands.

Source: TR-55, 1986.

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment [2]	Hydrologic condition [3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

1 Average runoff condition, and I_a=0.2S

2 Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.

3 Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Table E-7. Runoff curve numbers for other agricultural lands.

Source: TR-55, 1986.

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. [2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. [3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 [4]	48	65	73
Woods—grass combination (orchard or tree farm). [5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. [6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 [4]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

1 Average runoff condition, and $I_a = 0.2S$.

2 *Poor:* <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

3 *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

4 Actual curve number is less than 30; use CN = 30 for runoff computations.

5 CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

6 *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Table E-8. Runoff curve numbers for arid and semiarid rangelands.

Source: TR-55, 1986.

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition [2]	A [3]	B	C	D
Herbaceous—mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush.	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

1 Average runoff condition, and I_a, = 0.2S. For range in humid regions, use table 2-2c.
2 Poor: <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: > 70% ground cover.
3 Curve numbers for group A have been developed only for desert shrub.

E.5.8 Urban Impervious Area Modifications

Several factors, such as the percentage of impervious area and the means of conveying runoff from impervious areas to the drainage system, should be considered in computing CN for urban areas.

An impervious area is considered connected if runoff from it flows directly into the drainage system or if runoff occurs as shallow flow over a pervious area then into a drainage system. Runoff from unconnected impervious areas is spread over a pervious area as sheet flow. Urban CN's were developed for typical land use relationships based on specific assumed percentages of impervious area.

For connected areas, urban CNs (Table 5) were developed for various land use relationships based on an assumed percentage of impervious area.

To determine CN when all or part of the impervious area is not directly connected to the drainage system, (1) use Figure 5 if total impervious area is less than 30 percent or (2) use Figure 6 if the total impervious area is equal to or greater than 30 percent, because the absorptive capacity of the remaining pervious areas will not significantly affect runoff.

E.5.9 Time of Concentration and Travel Time

Travel time (T_t) is the time it takes water to travel from one location to another in a watershed. Time of concentration (T_c) is the time it takes water to travel from the hydraulically most distant point of the watershed to the point of interest. Factors that affect travel T_t and T_c are surface roughness, channel shape, flow patterns and slope.

Travel time, T_t is the ratio of flow length to flow velocity:

$$T_t = \frac{L}{3600V}$$

Where T_t equals the travel time (hr), L equals the flow length (ft), V equals the average velocity (ft/s), and 3600 if the conversion from seconds to hours.

Sheet flow occurs over land before water collects in streams. TR-55 uses the Mannings's kinematic solution to compute T_t for sheet flow of less than 300 feet.

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} s^{0.4}}$$

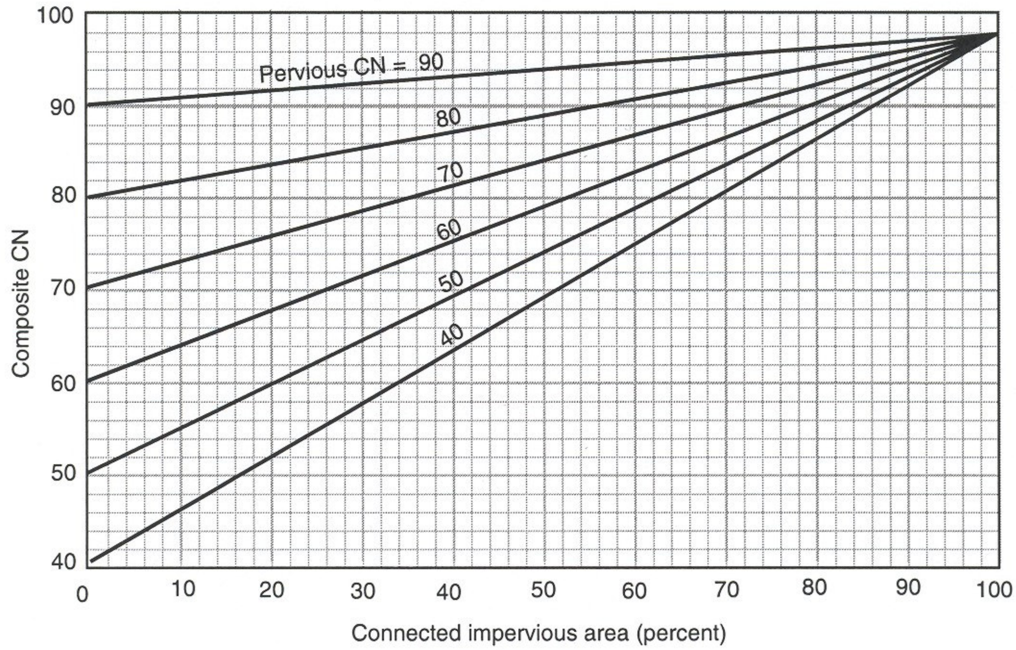

Figure E-5. Composite CN with connected impervious area.
Source: TR-55, 1986.

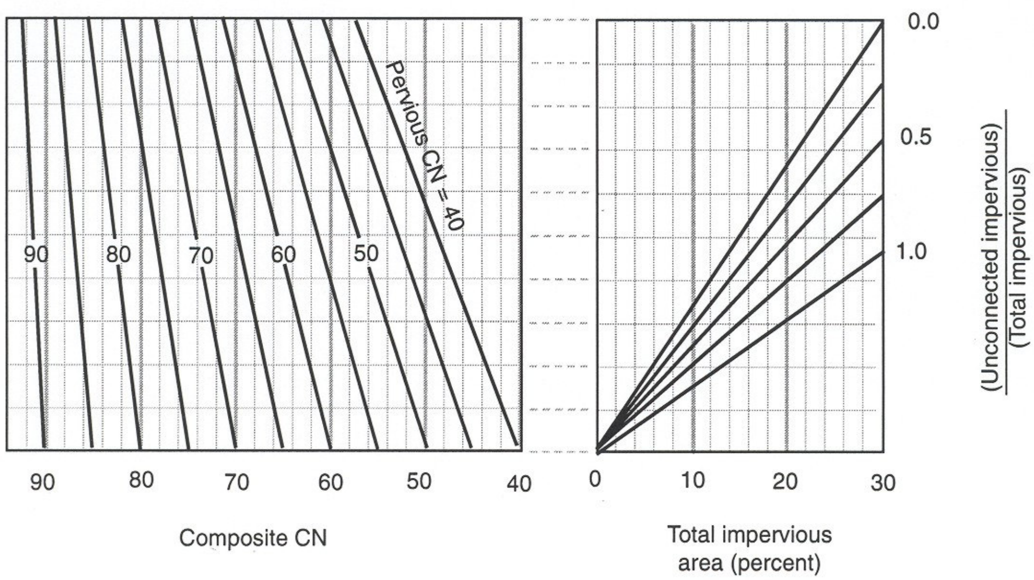

Figure E-6. Composite CN with unconnected impervious areas and total impervious area less than 30%.
Source: TR-55, 1986.

Where T_t equals travel time (hr), n equals Manning's roughness coefficient, L equals the flow length, P_2 equals 2-year, 24-hour rainfall (in), and s equals slope of hydraulic grade line (land slope, ft/ft). Table 9 provides Manning's n coefficients for shallow depths of about 0.1 foot.

Table E-9. Roughness coefficients (Manning's n) for sheet flow.

Source: TR-55, 1986.

Surface description	n [1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses [2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods: [3]	
Light underbrush	0.40
Dense underbrush	0.80

1 The n values are a composite of information compiled by Engman (1986).
2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
3 When selecting n , consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

After a maximum of 300 feet, sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined from Figure 7, in which the average velocity is a function of watercourse slope and type of channel. This velocity can be used to estimate travel time for the shallow concentrated flow segment.

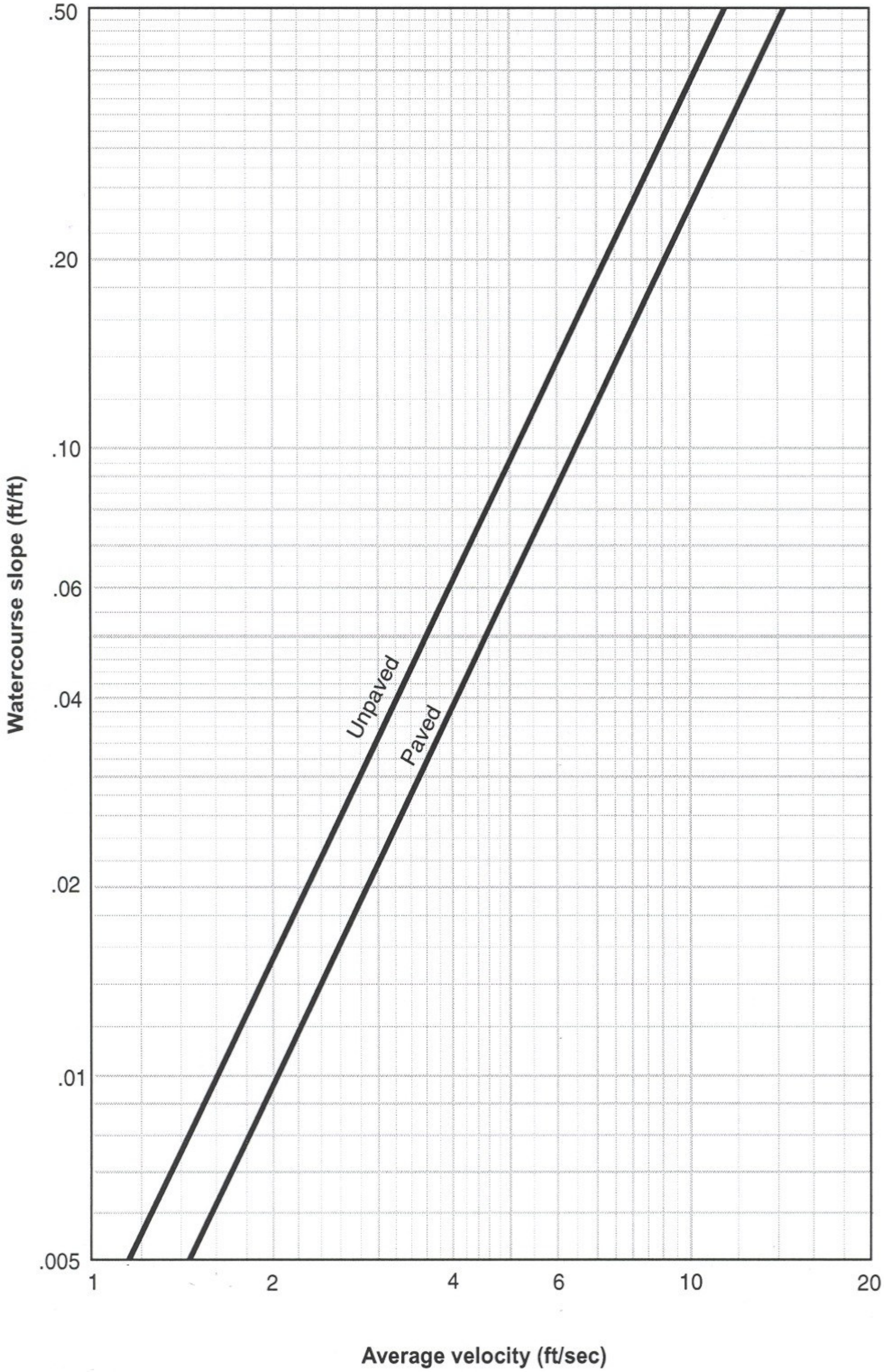
.50
.20
.10
.06
.04
.02
.01
.005
Watercourse slope (ft/ft)
Unpaved
Paved
1
2
4
6
10
20
Average velocity (ft/sec)

Figure E-7. Average velocities for estimating travel time for shallow concentrated flow.
Source: TR-55, 1986.

The Manning's equation can be used to estimate average flow velocity in open channels. Average velocity is usually determined for bank-full elevation.

$$V = \frac{1.49 r^{2/3} s^{1/2}}{n}$$

Where V equals average velocity (ft/s), r equals hydraulic radius (ft) and is equal to a/p_w, a equals to cross-sectional flow area (ft^2), p_w equals wetted perimeter (ft), s equals slope of the hydraulic grade line (channel slope ft/ft), and n equals Manning's roughness coefficient for open channel flow.

Travel time through lakes and reservoirs is small and can be assumed to equal zero.

E.5.10 Graphical Peak Discharge

Peak discharge is calculated using the following equation:

$$q_p = q_u A_m Q F_p$$

Where q_p equals peak discharge (cfs), q_u equals unit peak discharge in cubic feet of discharge per second per square mile of watershed per inch of runoff (csm/in), A_m equals drainage area (mi^2), Q equals runoff (in), and F_p equals pond and swamp adjustment factor. If pond and swamp areas are spread throughout the watershed and are not considered in the T_c computation, an adjustment for pond and swamp areas is also needed.

For the selected frequency, the 24-hour rainfall (P) is obtained from the Precipitation-Frequency Atlas from NOAA. A_m and Q have already been calculated in previous sections. The pond and swamp adjustment factor is obtained from Table 10 (rounded to the nearest table value).

Table E-10. Adjustment factor (Fp) for pond and swamp areas that are spread throughout the watershed
Source: TR-55, 1986.

Percentage of pond and swamp areas	F_p
0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

The remaining value to calculate is q_u. Rainfall patterns in California have been categorized to have three separate distributions as shown in Figure 8. The three types of rainfall distribution are Type I, Ia, II or III. The corresponding Figures (Figures 9 through 12) must be used to calculate q_u depending on the location of the stream. The CN is used to calculate the initial abstraction (I_a) and the ratio of the initial abstraction and precipitation (I_a/P) value is calculated. This ratio, in combination with the time of concentration, is used to calculate q_u.

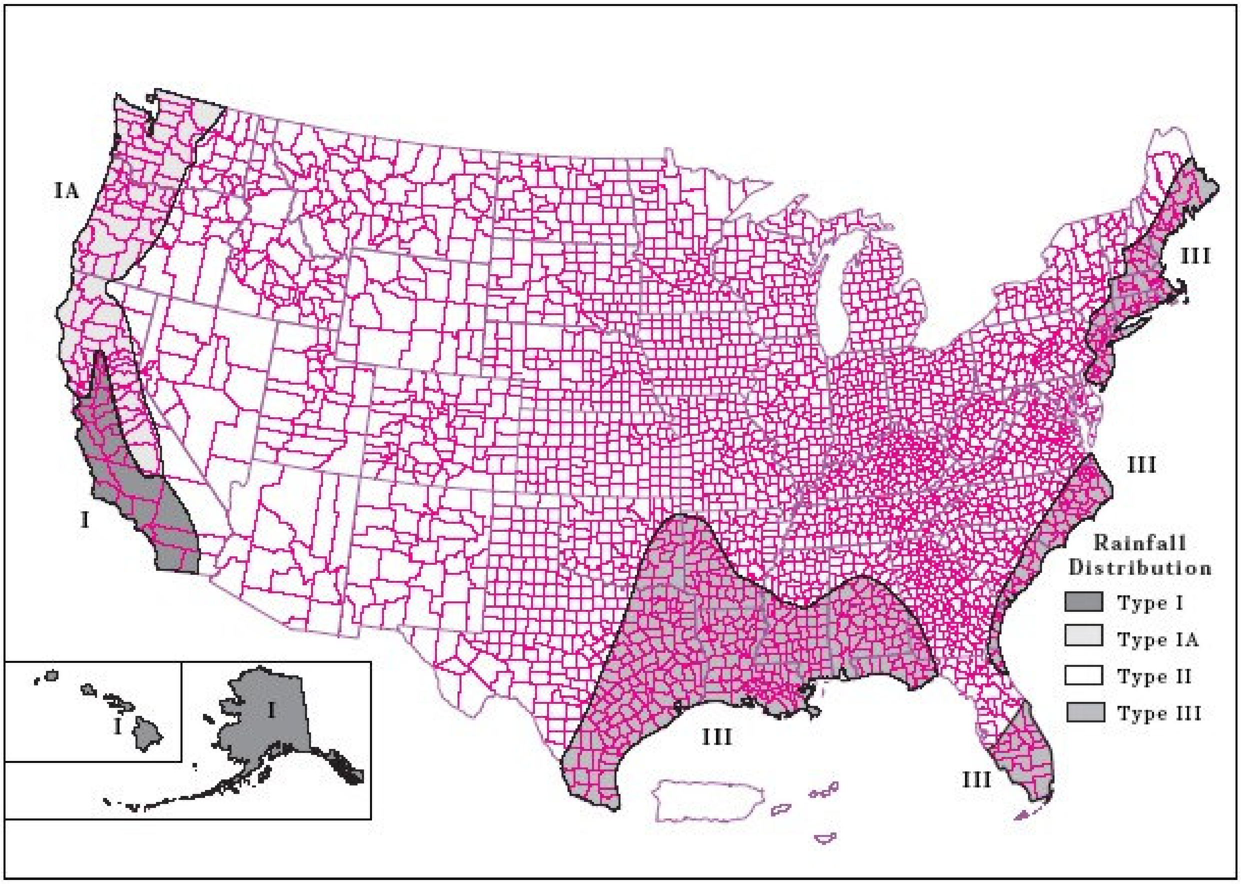

Figure E-8. Approximate geographic boundaries for NRCS (SCS) rainfall distributions.
Source: TR-55, 1986.

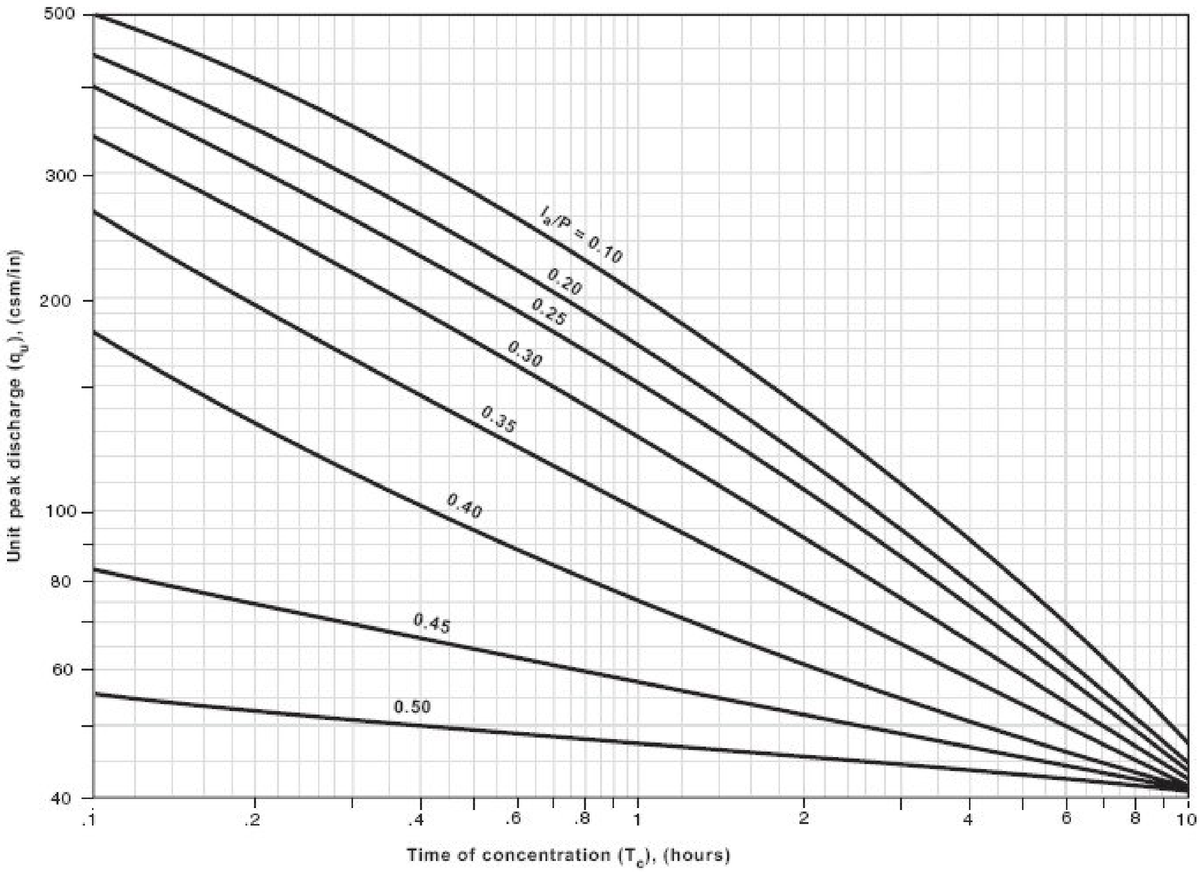

Figure E-9. Unit peak discharge (qu) for NRCS (SCS) type I rainfall distribution.
Source: TR-55, 1986.

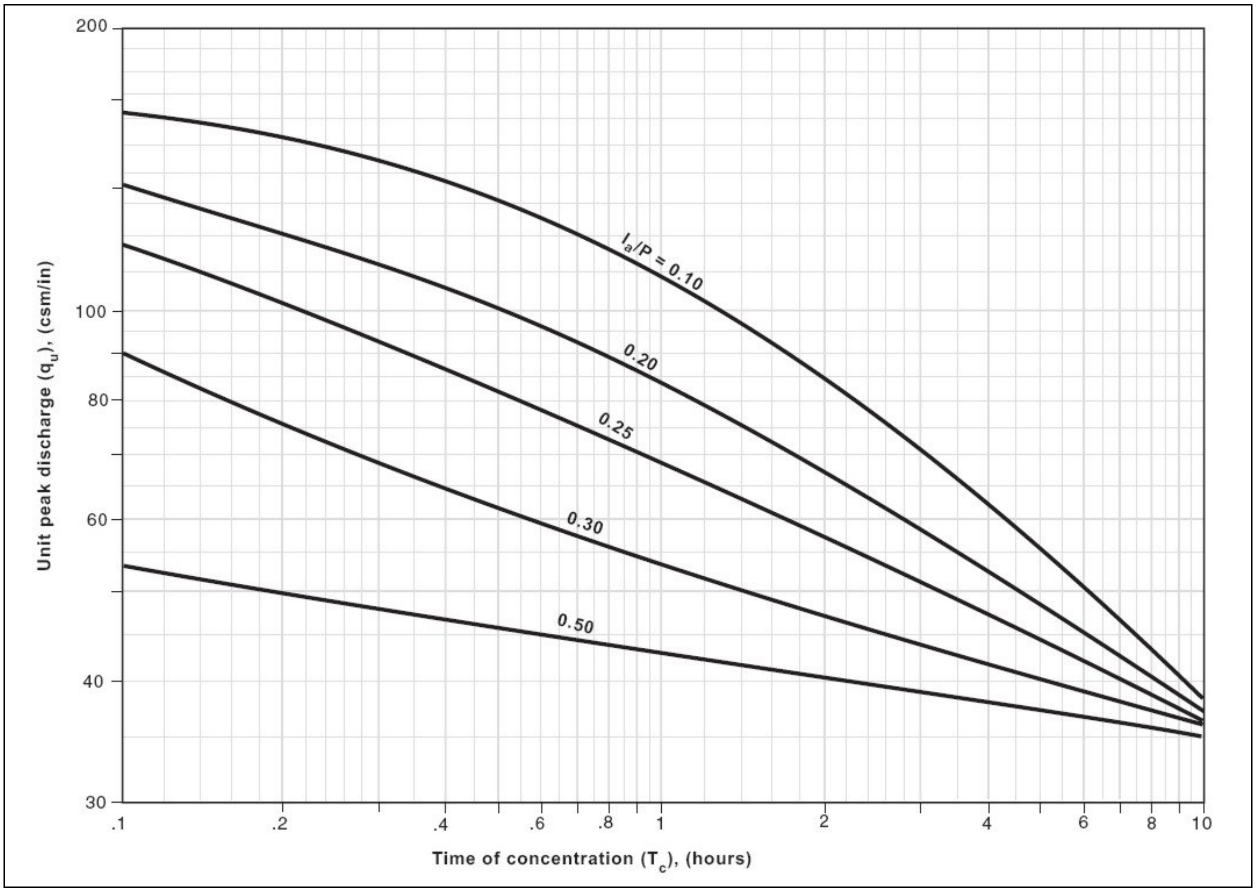

Figure E-10. Unit peak discharge (qu) for NRCS (SCS) type IA rainfall distribution.
Source: TR-55, 1986.

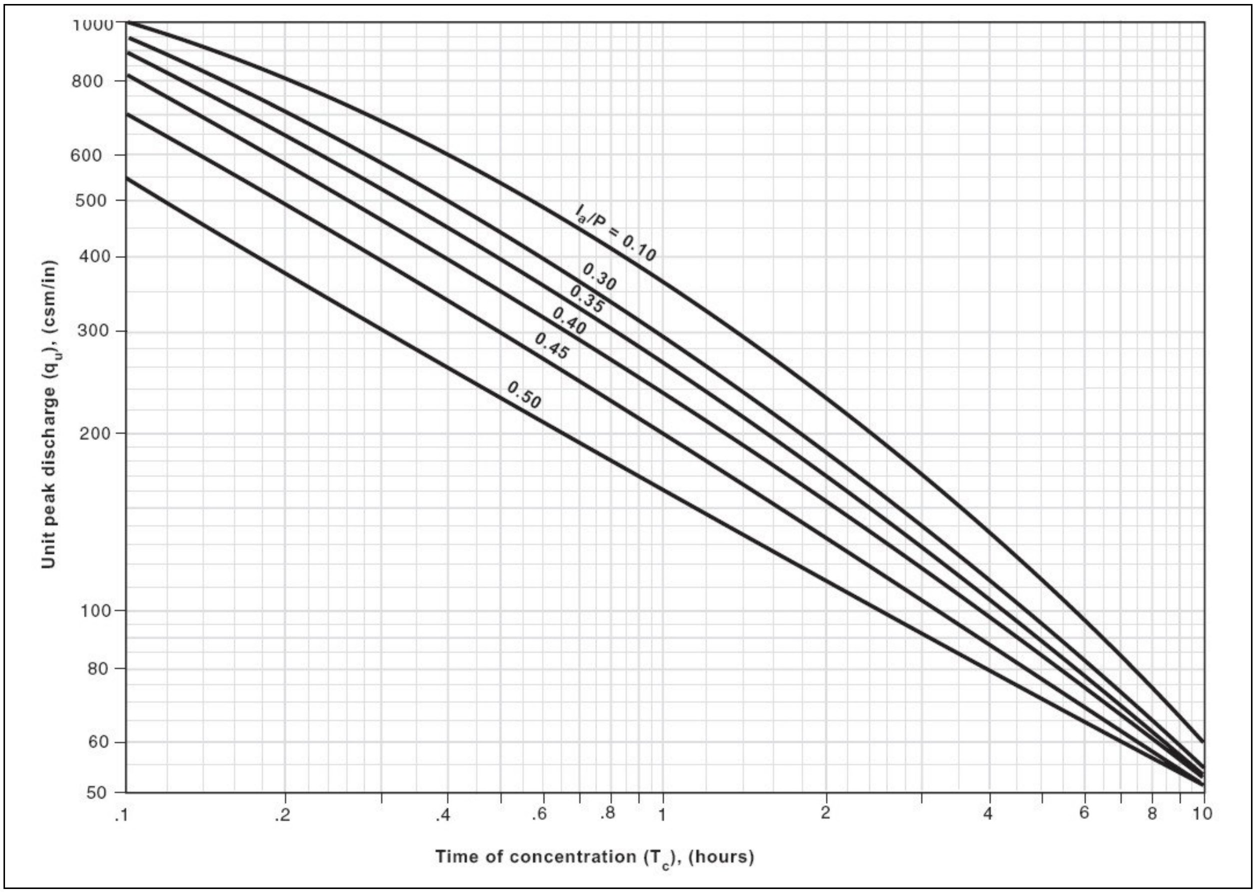

Figure E-11. Unit peak discharge (qu) for NRCS (SCS) type II rainfall distribution.
Source: TR-55, 1986.

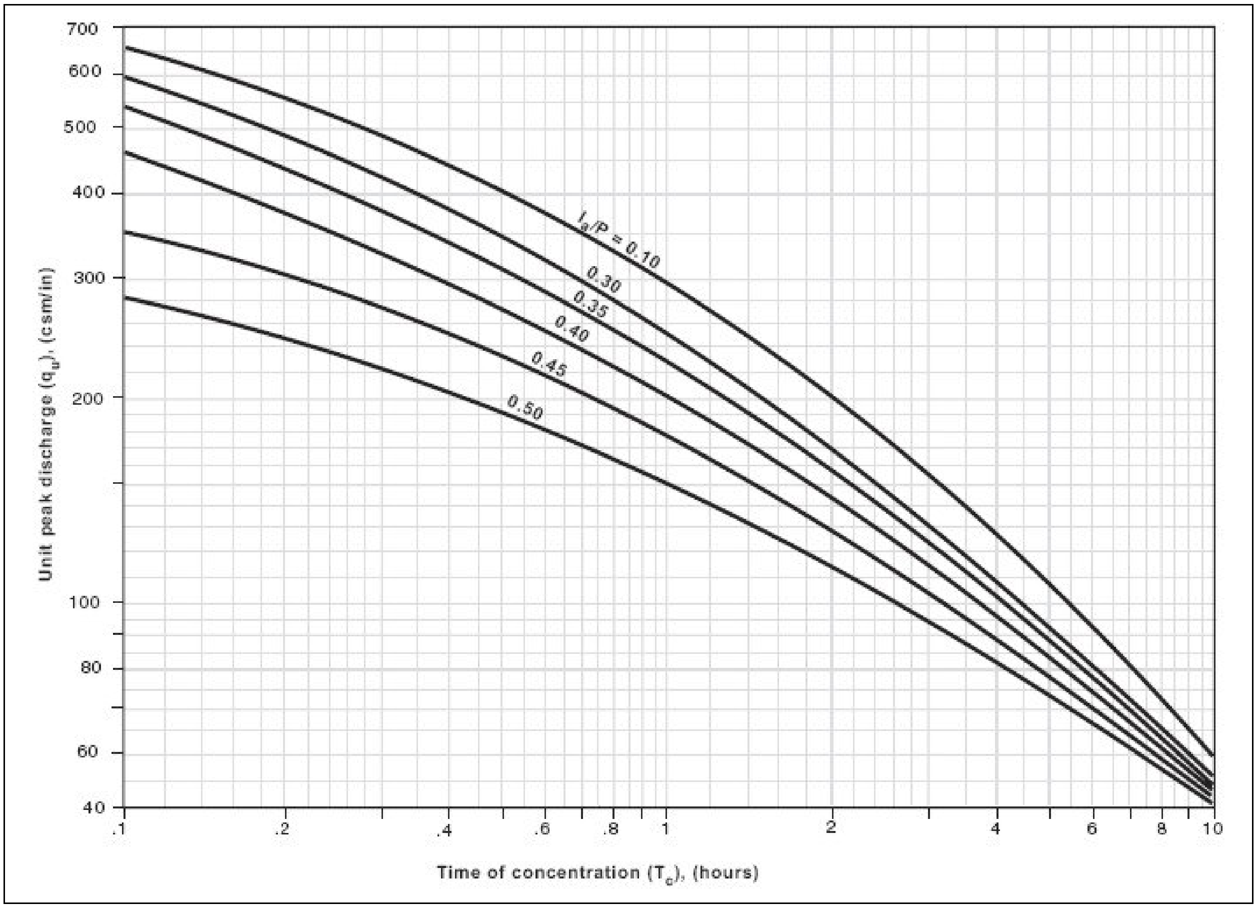

Figure E-12. Unit peak discharge (qu) for NRCS (SCS) type III rainfall distribution.
Source: TR-55, 1986.

Of the three methods, the TR-55 method is the most desirable if the designer has access to the required information. However there are some limitations to this method.

- The initial abstraction number is dependent upon the situation. It has been generalized with as 0.2S based on data from agricultural watersheds. This approximation can be especially important depending on the amount of urbanization of a watershed. Impervious areas increase with greater urbanization and therefore infiltration decreases. This should be considered when determining initial abstraction.
- Runoff from snowmelt or rain on frozen ground cannot be estimated using these procedures.
- The CN procedure is less accurate when runoff is less than 0.5 inch. As a check, another procedure to calculate runoff should be used.
- The SCS runoff procedure applies to direct surface runoff and does not consider ground water.
- When the weighted CN is less than 40, use another method to determine runoff.
- If water travels through sewer pipelines, the travel time through the pipe should be calculated with an appropriate pipe flow equation, such as Manning's equation for pipe flow.
- For further limitations refer to the TR-55 publication.

E.5.11 Example Calculations - TR-55 Method

For this method the example the watershed has the following characteristics:

- Stream is located in San Luis Obispo County
- Drainage Area = 2.95 mi2

<u>CN Calculation</u>

Cover is sagebrush with grass understory, fair
Grass is considered short prairie grass
Soil type - 20% of area is Serpentano (Type B), 80% of area is Lombard (Type C).

To calculate a CN, we use Table 8 - Runoff curve numbers for arid and semiarid rangelands. Because the hydrologic soil group is a mix of two types, we must calculate a composite CN. The CN for sagebrush with grass understory, fair and Serpentano (Type B) is 51. The CN for sagebrush with grass understory, fair and Lombard (Type C) is 63. The composite CN is then:

$$CN = 0.2(51) + 0.8(63) = 60.6$$

<u>Potential Maximum Retention After Runoff (S)</u>

$$S = \frac{1000}{CN} = \frac{1000}{60.6} - 10 = 6.5\,\text{in}$$

Initial Abstraction (I_a)

$$I_a = 0.2S = 0.2(6.5) = 1.3\,\text{in}$$

Runoff (Q)

Mean Annual Precipitation (P) = 8 in
2-Year, 24-hour Rainfall (P_2) = 4 in
100-Year, 24-hour Rainfall (P_{100}) = 8 in

$$Q_{2yr} = \frac{(P-0.2S)^2}{(P+0.8S)} = \frac{(4-0.2(6.5))^2}{(4+0.8(6.5))} = \frac{7.29}{9.2} = 0.79\text{in}$$

$$Q_{100yr} = \frac{(P-0.2S)^2}{(P+0.8S)} = \frac{(8-0.2(6.5))^2}{(8+0.8(6.5))} = \frac{44.9}{13.2} = 3.4\text{in}$$

Travel Time

Channel distance to outlet = 8000 ft
Average channel velocity = 1.3 ft/s

$$T_t = \frac{L}{3600V} = \frac{8000}{3600(1.3)} = 1.7\text{hr}$$

Peak Discharge (q_p)

2yr: $\frac{I_a}{P} = \frac{1.3}{4} = 0.325$

100yr: $\frac{I_a}{P} = \frac{1.3}{8} = 0.16\text{hr}$

From Figure 9 using Type I rainfall distribution using T_t and I_a/P:

2yr: q_u = 95 csm/in

100yr: q_u = 140 csm/in

2yr: $q_p = q_u A_m Q F_p = 95(2.95)(0.79)(1) = \underline{\underline{221\text{cfs}}}$

100yr: $q_p = q_u A_m Q F_p = 140(2.95)(3.4)(1) = \underline{\underline{1404\text{cfs}}}$